SELF-HEALING OF THERMAL CRACKS IN SANDWICH PANELS

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ABSTRACT

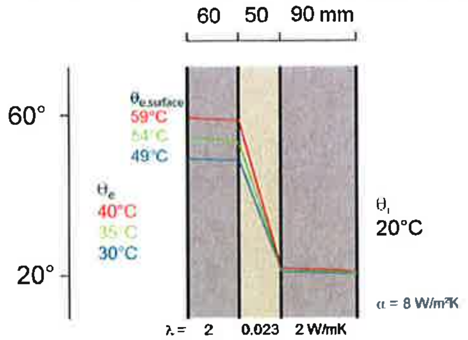
Sandwich panels are prefabricated, insulated concrete wall elements, which are sensitive to thermal cracking due to their composition (concrete outer cladding – insulation – concrete inner cladding). During hot days, the temperature of the outer concrete layer can rise up to ~ 60°C and the temperature difference between inner and outer layer causes crack formation in the outer concrete layer. Since cracking impairs the durability of concrete (e.g. accelerated corrosion of reinforcement steel by carbonation or chloride ingress), the aim of this research project is to regain impermeability and prevent esthetical damage through incorporation of self-healing capabilities.

At first, different healing agents (polyurethane (PU) and water repellent agent (WRA)) were screened based on their ability to regain impermeability and their behaviour upon reloading of cracked and healed samples. Two types of PU and three types of WRA were then selected to be applied in a real scale test.

For the real-scale test, the different healing agents were encapsulated by glass capsules and embedded in different zones in the outer layer of a sandwich panel (7.59 m x 1.20 m). After about 14 days, the test setup was built and the outer layer of the self-healing sandwich panel was thermally loaded up to temperatures of ~ 60°C for 9 hours per day. The temperature at the inner layer was kept constant at ~ 21°C. Due to the temperature difference, the panel bended, cracking occurred in the outer cladding, capsules broke and the healing agent was released. Some healing agents leaked out of the crack and left stains behind. Adaptation of the capsule volume, viscosity of the healing agent or concrete cover thickness over the capsules could solve this problem. PU and WRA were able to reduce the water permeability of cracks. Cracks treated with WRA remained water tight upon reloading, while PU can lose their bond with the crack surface resulting in an increased water absorption. In future research, more elastic polyurethanes, with a high bond strength to the concrete matrix, will be tested in order to solve this problem.

1. INTRODUCTION

Insulated sandwich panels which are exposed to sun radiation tend to bend because of the temperature difference between inner and outer concrete layer. This principle is schematized in Figure 2 and Figure 3 for a sandwich panel with a 60 mm outer concrete layer, 50 mm PU insulation and 90 mm inner concrete layer (concrete quality C30/37). The temperature of the concrete surface ($\theta_{e,surface}$) is higher than the outside temperature due to radiation.



a_S = 0.55 (absorption factor)
I_s = 850 W/m² (irradiation - short wave)
α_{re} = 4 W/m²K (radiative heat transfer coefficient)
α_{ce} = 19 W/m²K (convective heat transfer coefficient)
F_{ssky} = 0.5 (angle factor surface – sky)
$\Delta\theta_{sky}$ = 20°C (temperature difference between outside temperature and radiation temperature of the sky)

Figure 1: Temperature profile in a sandwich panel – outside temperature (θ_e): 40°C, 35°C or 30°C – inside temperature (θ_i): 20°C

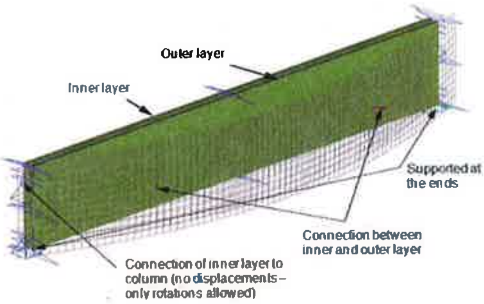


Figure 2: Bending of a sandwich panel under thermal load (simulation with the Scia Engineer software)

Tensile stresses in the outer concrete cladding (e.g. 8.3 MPa for the example given above with an outside temperature of 40°C) lead to cracking of the panels. These cracks impair the durability of the panels and are also unwanted from an aesthetical point of view. Especially after rainfall, the thermal cracks in sandwich panels are visible. In addition to PU healing agents, the use of WRA to eliminate water penetration into the cracks has therefore also been investigated.

2. HEALING AGENTS

The healing agents should be able to reduce the water permeability of the cracked concrete. In order to evaluate this ability, the capillary water absorption of cracked and manually healed specimens (40 x 40 x 60 mm – crack width: 50 – 150 μm after unloading) was compared. Based on the test results, three types of WRA were selected. Also the PU healing agents will be considered in further tests. WRA 1, 2

and 3 are respectively silane based, silane-siloxane based and siloxane-acrylate based agents.
The behavior of the healing agents upon reloading of cracked and healed specimens (40 x 40 x 160 mm) is presented in Figure 3 (WRA 1, 2, 3 and PU1). The cracks treated with WRA grew upon reloading, but the crack faces were impregnated with the WRA. As a consequence, the sorption coefficient remained low. PU bonded to the mortar matrix and filled the crack, so a new crack appeared or the connection between PU and mortar was lost upon reloading. As a consequence, the capillary sorption coefficient increased.

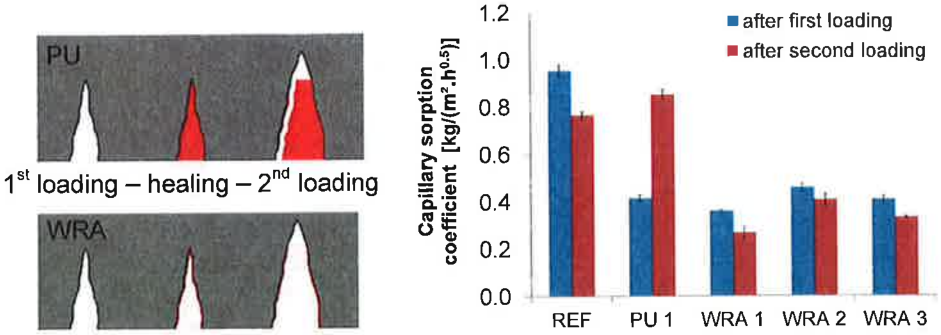


Figure 3: Crack formation during loading and reloading (left) – Capillary sorption coefficient of cracked and healed specimens before (blue) and after (red) reloading (right).

3. SIMULATION OF THERMAL CRACK FORMATION ON LAB-SCALE

In a real scale test set-up in the laboratory, sandwich panels (7.59 m x 1.20 m) made of self-healing concrete, were thermally loaded and the self-healing efficiency of 3 types WRA and 2 types PU (PU 1: one component PU – PU 2: two-component PU) was evaluated. The healing agents were encapsulated by glass capsules (Ø 3 mm) which were placed in zones per healing agent along the length of the panel (Figure 4). The capsules and reinforcement were placed in the mould and concrete was poured. During compaction, the capsules rose and were embedded in the concrete.

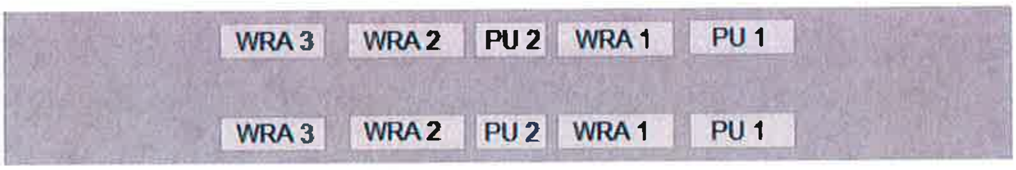


Figure 4 : Position of the capsules in the panel (PU 1: 2 x 95 capsules – PU 2: 2 x 2 x 50 capsules – WRA 1: 2 x 100 capsules – WRA 2: 2 x 100 capsules – WRA 3: 2 x 80 capsules)

After ~ 14 days, the test setup was built (Figure 5) and the outer cladding of the panel was heated until the surface temperature reached ~ 60°C (to simulate an outside temperature of ~ 40°C – see introduction). The inner cladding was exposed to an environment of ~ 21°C. To simulate the day-night effect, the panels were exposed to a thermal cycle of 24 hours (heating for 9 hours per cycle).

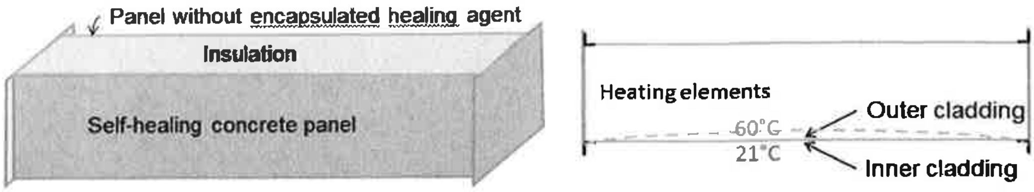


Figure 5: Laboratory test setup (3D view (left) – top view (right))

4. RESULTS

Due to the high temperature differences between inner and outer concrete layer, the panels bended and displaced over ~ 10 mm (measured by LVDTs in the middle of the panels). After the first heating cycle, cracks already appeared and capsules broke. Small cracks of ~ 20 μm, seemed to be enough to trigger breakage of the capsules. However, the early breakage of the capsules was mainly attributed to the small concrete cover on the capsules (~ 2 mm).
Due to the small crack width, the amount of healing agent released from the capsules was too high in comparison to the crack volume. Moreover, because of the high temperature, the viscosity of the healing agents decreased. As a consequence, the healing agent leaked out the crack. PU ran down the crack, leaving behind a long stain, while WRA 1 created dark stains on the surface (Figure 6). The colour difference, measured by a spectrophotometer, between these stains and untreated concrete fades away in wet conditions. No stains were detected in the zones with WRA 2 and WRA 3. In these zones, few cracks were formed and there was no certainty that capsules broke.
The water tightness, measured by the Karsten tube method, could be regained at places were the cracks healed autonomously (PU or WRA), but only for cracks < 100 μm.

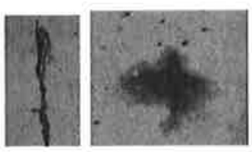


Figure 6: Breakage of capsules due to cracking in a zone containing capsules filled with PU 1 (left) and a zone containing capsules filled with WRA 1 (right).

5. CONCLUSIONS

The natural process of thermal crack creation in sandwich panels could be simulated in the laboratory. Thermal cracks were formed in the outer layer and healing agent was released. The capsules broke in an early stage due to the low concrete cover on the capsules and the healing agent leaked out of the concrete due to the small crack width. Adaptation of the capsule volume, viscosity of the healing agent or concrete cover thickness could solve this problem.

Polyurethanes and water repellent agents were able to reduce the water permeability of cracks. Cracks treated with water repellent agents remained water tight upon reloading, while polyurethanes can lose their bond with the crack surface resulting in an increased water absorption. In future research, more elastic polyurethanes, with a high bond strength to the concrete matrix, will be tested in order to solve this problem.

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